MECHANICAL AND THERMAL BEHAVIOUR OF SEQUENCE WOVEN METAL MESH INTERTWINED WOVEN BASALT/JUTE FIBER EPOXY POLYMERIC COMPOSITE

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Abstract:

Designing a fiber reinforced polymer composite requires careful consideration of the various Fibers used how they are stacked, the fiber ratio, and position of different fiber layers, as these factors influence the structural characteristics. The research is mainly focused on the development of a new class of metal fiber polymer laminate-MFPL (woven stainless-steel mesh/basalt/jute) and its performance studies. Woven stainless-steel mesh reinforcement acts as a high-impact load absorber and as a high-ductile. The new class MFP laminate design was created by utilizing a Vacuum assisted resin transfer moulding technique (VARTM). The study looked at the mechanical characteristics of the produced MFPL, including tensile and flexural strength. The stacking layering arrangement with alternating basalt and jute layers demonstrated greater flexural and tensile strengths, by basalt layers on the outer locations. The thick basalt fiber may hold tension, especially in the outer layer, decreasing stress transmission to the remaining core layers. The wire mesh composed of basalt and jute fiber, with alternating layers and basalt layers on the outside, demonstrated a to some extent lower thermal degradation (364 °C) compared to the composite with basalt covered layering arrangement (462 °C). The outer basalt layers' strong thermal resistance limits heat passage to the following fiber layers.

Keywords: Jute fiber; Basalt mineral fiber; Layering arrangement; Polymer composite; Mechanical behaviour Thermal properties.

1.Introduction

Natural Fiber is increasingly being used as reinforcing materials as a result of recent breakthroughs in polymeric composite composites. It is required for the design of sophisticated structural components for a variety of applications, including civil structures, automotives, low-cost housing, furniture, consumer products, marine, and so on. Polymer composites made from natural fibers are lighter and better for the environment than synthetic glass fiber-reinforced polymer composites [1-4]. Natural fibers such as oil palm, jute, pineapple, hemp, oil palm, pineapple, abaca, sisal, ramie, banana, bamboo, kenaf, coir, and other plant based fibers are organic and known as bio-fibers. Jute fiber is considered to have the most important properties among these natural fibers [5, 6].

Another high-strength natural fibre is mineral basalt fibre, which is the least expensive and most environmentally friendly alternative to glass fibre. Furthermore, basalt fibre has excellent thermal stability, water resistance, and appealing electrical insulating qualities [7-8]. Natural fiber composite materials have gained popularity over bulk materials in numerous industries such as automobiles, building, household goods, and space due to their versatility. However, normal fiber unaccompanied may not be suitable for certain bids due to its instability.Toovercome this, sandwich/hybrid/composite techniques can be used. Hybridization techniques have proven effective in addressing disadvantages of natural mono-fiber composites [9, 10]. By combining wire mesh, fibers and using a specific loading sequence, hybrid composites offer added advantages in property enhancement, making them appropriate for locomotive and building applications [11-13]. Polymer composites are produced by stacking individual fiber layers or by mixing them with other fiber components. The characteristics of composite materials are predisposed by factors such as the type of reinforcement, the number of fiber stacking layers, the positioning of woven fibers, fiber-matrix adhesion, fiber orientation, fiber content, and the production procedure [14-16].

In recent times, metal- fiber laminates (MFPL) have been extensively used in the aviation industry as a monolithic material. Researchers tried working with assorted fibers and metals for the development of MFPLs [17]. Common metals such as aluminium and steel, used in the form of sheet or mesh wire, etc., were tried based on the requirements of structure for that specific application. Wire mesh was laminated with basalt, glass, aramid, carbon, banana, jute fiber, etc. [17-19]. The researchers created a mixture composite by combining stainless-steel wire mesh (SSWM), GFRP woven roving, and Epoxy resin. The resulting hybrid composite consisted of a layer of mesh made of stainless steel in the center, laminated among both glasses woven fabric. The researchers then studied the shear, flexural, ductile, and impact strong point of the mixture composite [20]. Khan et al. [21] investigated certain important features of jute fibre and confirmed that it has some substantial mechanical qualities. In addition, jute plant fibers have pectin, low wax, and water-soluble ingredient content, which results in terms of hardness and shock absorbing.

Previous research has shown that modifying the position and layering arrangement of fibers can progress the mechanical and thermomechanical properties of polymer compounds. Thermal and mechanical characteristics of hybrid composites will be validated before being used in real applications, particularly for automotive end applications that require innovative lightweight materials. The study's goal is to create a composite material made solely of natural materials like basalt mixed jute fibers. The study aims on the expansion and performance analysis of a novel type of metal fiber polymer laminate (MFPL) consisting of woven stainless-steel mesh/basalt/jute. The woven stainless-steel mesh reinforcement provides high impact load absorption and ductility. The current study investigates the thermal and mechanical characteristics of epoxy polymer mixtures by woven layering arrangements of wire mesh with basalt/jute fiber. The research also examines the result of weave layers arrangement on the core layers' exterior and inner surfaces of the entangled composites.

2. Materials and methods

2.1 Woven stainless steel wire mesh, woven jute fabric, woven basalt fabric and epoxy resin

Vasavibala Resins, an Indian company, supplied the epoxy as a polymer matrix. Hardener and curing agent were used in a 1:10 ratio for the composite preparation. The jute and basalt fabrics used in this study were supplied by Gogreen Products-India. The jute fabric was 0.4 mm thick, while the basalt fabric was 0.26 mm thick. The warp orientation of the jute fabric was 90°, while the weft orientation of the basalt fabric was 0°. Jute fiber has a density of 1.4 g/cm3 and a ductile strength of 1034 MPa. The woven basalt material serves as a strong fibre. Developing interwoven composite composites required a robust damping reinforcing material, and jute fibre provided this. Basalt fibre has the density of 2.7 g/cm3 and a tensile strength of 4750 MPa. Jute and basalt fibre were subjected to alkaline and acetylene surface modification treatments to increase matrix-reinforcement adhesion.

2.2 Manufacturing of layered jute composites with the influence of basalt fiber placement

Using VARTM process, a laminate composed of steel wire mesh, jute, basalt, and epoxy was created, which is considered the most promising method. A compression load of 10 MPa was continued throughout the procedure. After being subjected to direct sunshine for 24 hours, the composites were treated in a heater for 60 minutes around 70°C. The dissimilar woven layering configurations (WLA-I, WLA-II, WLA-III, and WLA-IV) used in the composites and entangled composites produced are depicted in Figure 1. Weight fractions of the matrix and fiber for the woven layering arrangement composites are listed in Table 1. The fiber arrangements used in the composites were identified as woven wire mesh (W), woven basalt fiber (B), and woven jute fiber (J).

Figure 1: Jute fiber location and layer arrangement of composites

2.3 Experimentation of flexural and tensile

ASTM D638 standard was followed to create dog bone-shaped tensile specimens. The specimens were then subjected to tensile testing making use of a Universal Testing Machine (UTM) containing two grips. The specimen was positioned between both grips and the stretchable side was moved at a steady velocity of 5 mm/min. The strength and stiffness of the generated composites were tested using the ASTM D790 standard. For this aim, a three-point bending testing was coupled to the same UTM. Standard and broken characteristic flexural and tensile test samples are shown in Figure 2 (a-c) and 3 (a-c). The five specimens were tested and a standard deviation was reported for each testing condition.

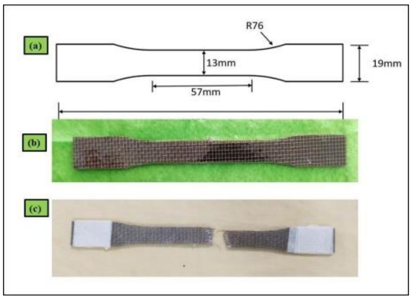

Figure 2 (a) Standard size tensile specimen, (b) Tensile WBJBJW composite specimen, and (c) Tensile cracked WBJBJW composite

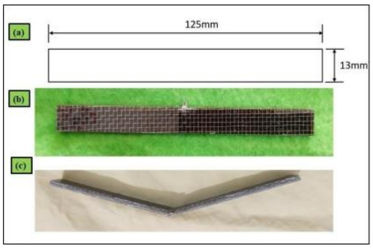

Figure3(a) Standard size flexural specimen, (b) Specimen for flexuralWBJBJWcomposite,and(c)Specimen for flexuralfracturedWBJBJWcomposite

2.4 Thermogravimetric analysis

The researchers utilized TGA-SDT 2960 apparatus that combines DSC-TGA to assess thermal properties of basalt and jute fibers, as well as their epoxy composites. The study's sample group was 10 mg, and thermal degradation was investigated in a nitrogen environment at a continuous temperature increase of 10°C/min in the temperatures range of 30 to 600°C. TGA method was employed in a controlled setting to measure weight loss at dissimilar temperatures and to identify the dilapidation temperatures of woven layering arrangement composites.

3. Results and Discussion

3.1 Woven layered laminate flexural and tensile analysis

Figure 4 illustrates impact of various stacking configurations of natural basalt interlaced jute fiber composites on their tensile modulus and strength (WLA-I, WLA-II, WLA-III, and WLA-IV).

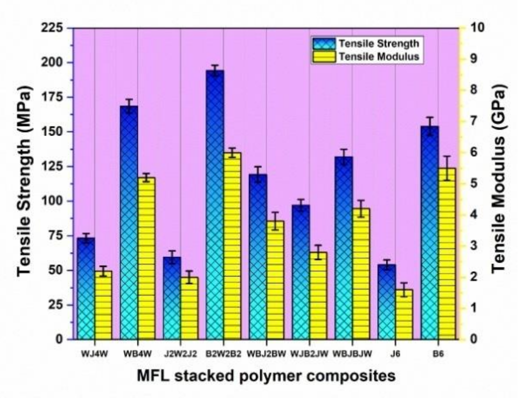

Figure 4 Mechanical properties Modification Of Jute Fiber Location In Polymer Composites

WLA-V control samples revealed that the clean basalt B6 composite had higher modulus and tensile strength than the J6 (jute fiber) composite, owing to the fact that basalt fiber is tougher than jute fiber. The ultimate tensile and elasticity of the WLA-I fabric layer layering configuration composites are significantly influenced by the position and number of fabric layers. The WB4W composite's woven layered layering arrangement had a greater tensile strength than the skin wire mesh with core jute fabric composite (WJ4W). Also, the inclusion of high-strength basalt fiber layers altered the tensile properties of the WB4W composites. In the WB4W woven layering design, the tensile strength was high and demonstrated a 111% increase over the WJ4W layering arrangement composite. In the WLA-II design, the skin/outer woven material layers determined the ductile strength and modulus, where B2W2B2 composite had better tensile strength than J2W2J2. The interlaced layering structure arranged alternately in the WLA-III interwoven laminates, and WBJ2BW design had higher tensile strength than WJB2JW stacking composites. The study consequence is reliable with the research conducted by Srinivasan et al. [22] where the jute-banana natural fiber mixed with epoxy mixtures using an exterior skin layer, E-glass fiber is used and demonstrated greater tensile strength than other stacking multilayer composites.

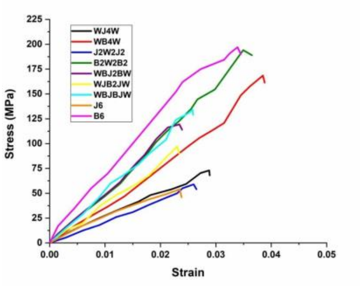

Figure 5 Stress-strain curvature of MFL composites

Figure 5 illustrates the stress-strain behaviour of WLA composites with various stacking arrangements, which were tested to contrast the effects having both great and low strength fiber placements on the test samples. Figure 5 displays the B2W2B2 merged had the highest toughness compared to all other WLA composites because of the strong interfacial adherence between the skin basalt fiber as well as the matrix, whereas B2W2B2 composite had higher elongation than the J2W2J2 layering arrangement laminate. Toughness of the WLA composites among pure basalt and jute composites determined tensile curves of woven layered layering arrangement composites. Additionally, as more basalt layers were added, the elongation to break decreased even though basalt fiber grows brittleness of the composites to some extent. The WBJ2BW woven layered layering arrangement composite had a higher strain than the WJB2JW. The rigidity of the WLA composites was also affected by the outer layer fiber's strength and toughness of the tensile curvature, as demonstrated in the research of Ramesh et al. [23], who found that glass fibers are employed in the laminate's outer layers, the tensile strength increases.

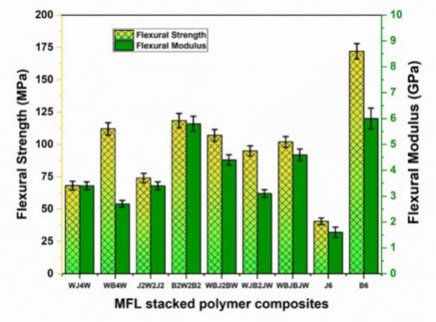

Figure 6 Flexural strength variation of jute fiber location in polymer composites

The figure 6 illustrates different modulus of elasticity and stiffness values woven layering patterns (WLA-I, WLA-II, WLA-III, WLA-IV, and WLA-V) manufactured composites. B6 flexural strength and modulus values of the composite were greater than those of pure jute. (J6) and basalt (B6) composites (control samples), was due to the increased bending strength of basalt fiber. Various type of core layers affected the flexural strong point and modulus of the WLA-I (WJ4W & WB4W) composites. In the WJ4W layering arrangement, the strain in the surface jute coating was quickly transported to the basalt layer core bundle, which limited bending weight. The WLA-II composites, particularly the B2W2B2 design, had stronger flexural strength associated with the J2W2J2 composite. Outermost layers of composites bending stress was retained, minimizing stress transmission to the core layers. This was consistent with the findings of Amico et al. [24]. The WLA-III composites (WBJ2BW and WJB2JW) flexural strength was impacted by a high-strength outer fiber and an alternative layer. The experimental results demonstrated that the addition and placement of a substantial number of basalt layers interlaced with epoxy composites improved their mechanical properties.

3.2 Fracture Surface Analysis

The images in Figure 7 (a-f) display the cracked surfaces of the composite tensile samples that were loaded. These specimens consisted of uncontaminated basalt, pure jute, and mixture composites, which exhibited various types of fiber failure, including fiber breakage, pullout, splitting, and debonding from the epoxy matrix. The WB4W composite, shown in Figure 7 (c), demonstrated fiber splitting in both transverse and longitudinal orientations. In contrast, frail attachment interaction amongst the fiber and matrix resin in the WJ4W composite, leading to fiberpullout and void formation, as seen in Figure 8 a. B2W2B2 and B2W4B2 had similar failure characteristics, including fiber breaking, as illustrated in Figure 8 d. In addition, fiber breaking was discovered in a direction perpendicular of the WBJ2BW composite, as revealed in Figure 8 b. The results are reliable with previous research on hybrid natural polymer fiber composites surface fracture by Fiore et al. [15].

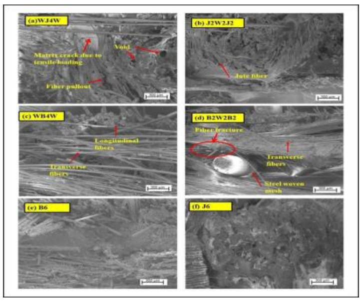

Figure 7 Typical tensile fracture SEM images of WLA composites

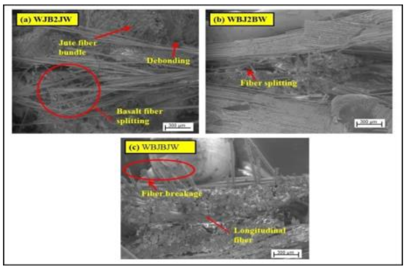

Figure 8 Typical tensile fracture SEM images basalt/jute/ wire mesh composites

3.3 Thermo gravimetric analysis

The figure 9 illustrates TGA curvatures of various interlaced composites. The use of wire mesh interwoven with jute and basalt composites in both skin and core layers significantly affects their thermal possessions. In addition of basalt fiber to composites enhances their thermal stability, pushing the start and terminal degradation temperatures to higher ranges the quantity of basalt fiber layers grows. The TGA curves designate three stages of weight loss: preliminary mass loss (about 5%), considerable mass loss (80%), and ultimate mass loss near the final of the degradation curvatures. Table 2 shows the stating and highest mass loss temperatures for different woven layering arrangement composites. The starting mass loss in these composites is mainly due to moisture removal from the jute fiber, while the additional stage of mass loss is caused by epoxy volatilization and fiber breakdown. The final weight loss is due to residue loss, matrix, and fiber degradation. Pure basalt composite exhibits very little weight loss as it has greater thermal stability than jute fiber, even at high temperatures.

The skin basalt layers in WLA composites significantly increases thermal resistance. The composites of B6 and B2W2B2 have higher thermal stability than earlier woven layered arrangement composites. Pure basalt layered composites exhibit the highest thermal resistance (462°C) among the interlaced composites. Alternating basalt coatings limiting temperature flow to jute coatings could be the reason for this temperature resistance in hybrid mixtures.

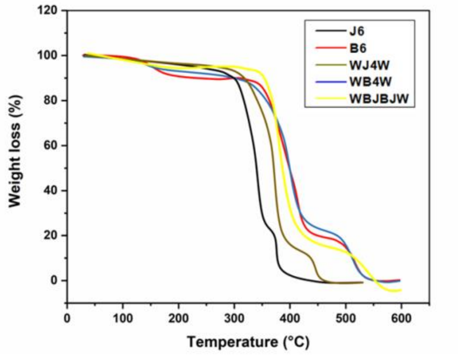

Figure 9 Thermal characteristics of MFL layered composites

Table2ThermalexaminationofWLA-I, WLA-II, WLA-III, WLA-IV& WLA-Vcomposites

Explanation	**Categoriesofcomposites**	**Degradationtemperature (°C)**	
		Initial degradation	**Majordegradation**
WLA-I	WJ4W	282	340

	WB4W	326	392
WLA-II	J2W2J2	278	328
	B2W2B2	330	408
WLA-III	WBJ2BW	315	380
	WJB2JW	308	359
WLA-IV	WBJBJW	320	364
WLA-V	J6	275	334
	B6	342	462

4. Conclusions

The primary aim of this research is to investigate mechanical and thermal performance of composites made of interlaced basalt and jute fibers with skin and core layers of woven wire mesh, and to design a new polymer WLA based on these materials. The mechanical properties of the composites are significantly influenced by the type and number of skin fiber layers and the stacking layering arrangement of the wire mesh with basalt/jute fibers. The composites' tensile stress-strain curves revealed a non-linear connection between tensile stress and strain. Fracture surface analysis reveal the fiber breakage, matrix crack, fibersdebonding of basalt intertwined jute fiber composite composites, in addition, matrix fracture observed between jute layers.The stiffness of the composite dropped steadily as the number of jute fiber layers in the planned composite increased. The pure jute laminate had a higher elongation to break, whereas the pure basalt laminate had a lower elongation to break. Basalt layers behave as insulators, increasing thermal resistance. Finally, the research demonstrates that basalt/jute fiber weaving in polymer composites has a considerable influence on mechanical strength.

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